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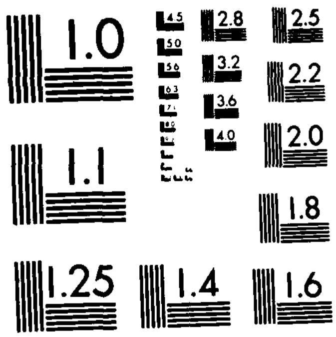

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by

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Abstract

On 19 May 1978 an unusual series of events is observed with the Quadrispherical LEPEDEA on board the ISEE-1 satellite in the earth's geomagnetic tail. For 13 hours periodic bursts of both ions and electrons are seen in all the particle detectors on the spacecraft. On this day periodic activity is also seen on the ground, where multiple intensifications of the electrojets are observed. At the same time the latitudinal component of the interplanetary magnetic field shows a number of strong southward deflections. We conclude that an extended period of substorm activity is occurring, which causes repeated thinnings and recoveries of the plasma sheet. These are detected by ISEE, which is situated in the plasma sheet boundary layer, as periodic dropouts and reappearances of the plasma. Comparisons of the observations at ISEE with those at IMP-8, which for a time is engulfed by the plasma sheet, indicate that the activity is relatively localized in spatial extent. For this series of events it is clear that a global approach to magnetospheric dynamics, e.g., reconnection, is inappropriate.

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1. Introduction

In most studies of substorm effects in the geomagnetic tail, emphasis has been placed on plasma flows (Bieber and Stone, 1980; Belian et al., 1981), and magnetic field topology (McPherron et al., 1973; Hones et al., 1982). Such an approach has led to development of the near-earth neutral line model of substorms. In this model a neutral line is supposedly formed by reconnection of the earth's magnetic field lines with those of the solar wind, forming an x-type neutral line extending from dawn to dusk (Hones, 1972). In the vicinity of the neutral line energetic streaming should be observed (Schindler, 1974; Birn, 1980), as the neutral line moves tailwards. Magnetic field rotation occurs in conjunction with streaming and plasma dropout.

In the present work we have examined a period of unusual activity in the tail, using primarily the LEPEDEA instruments on ISEE-1 and IMP-8, focussing directly on the actual plasma distribution. On 19 May, 1978 both ISEE-1 and IMP-8 are in the tail, with ISEE-1 approximately 10-15 R_E from the earth and IMP-8 10 R_E further downstream. At ISEE the ion and electron distributions show periodic dropouts and reappearances over 13 hours. From ground-based observations of the magnetic field we are able to determine that weak substorm activity occurs on the same day. The H component shows quasi-periodic fluctuations at a number of stations and the AE index rises during this period. The magnetic field measured in the tail magnetosheath by IMP-8 also shows surprising variations in B_z, with several periods of strong southward field observed. Thus it seems that the plasma sheet is undergoing periodic thinnings and recoveries for an extended period due to substorm activity. Our examination of the plasma distributions both at ISEE-1 and IMP-8 reveals a number of interesting facts concerning the tail response associated with geomagnetic activity.

2. Instrumentation

The observations presented here are from the University of Iowa LEPEDEA instruments on ISEE-1 and IMP-8, and the Goddard Space Flight Center magnetometer on IMP-8. Additional information is provided by the medium energy particle detector on ISEE-1. The LEPEDEA plasma instrument on ISEE-1 is described by Frank et al. (1978). For this day the instrument samples electron and positive ion intensities in 32 energy pass-bands from 215 eV to 45 keV, with an energy resolution of $\Delta E/E = 0.16$. At each energy level 16 azimuthal sectors are covered in 16 seconds, while 7 polar angles are simultaneously sampled in each azimuthal sector. Thus a full three-dimensional distribution consisting of 112 angular samples at each energy level, giving 3584 sections of velocity space, is obtained in approximately 8 minutes.

Survey energy-time (E-t) spectrograms of the plasma measurements are used in our analysis. An example is shown in Plate 1A for the period 0000 to 2400 UT on 19 May 1978. This spectrogram displays detector response on a color-coded scale as shown to the right. The upper four panels display the detector responses to ion intensities in four solid angle segments near the solar ecliptic plane. From top to bottom these are for ion velocities directed antisunwards, dawnwards, sunwards and duskwards, respectively. The fifth panel shows the electron intensities averaged over all azimuthal sectors, in a plane near the solar ecliptic.

Color-coded E-ϕ spectrograms provide samples of the velocity distribution in terms of energy versus azimuth for each of the seven polar angles. Plate 2 shows examples of such spectrograms. Displayed are responses of each of the seven ion and electron detectors and of the Geiger-Mueller tube. The

detectors are numbered 1P through 7P for ions, where the look angles range from 13° from the spacecraft spin axis (1P) through 90° (4P) to 167° (7P). A similar polar range is displayed for the electron channels numbered 1E through 7E. The GM tube measures particles above a fixed energy as a function of azimuthal angle. This detector responds primarily to electrons with $\gtrsim 45$ keV. Starting from the lowest energy step each detector sweeps through all azimuthal angles (ϕ) before stepping up to the next energy level.

The LEPEDEA on the IMP-8 spacecraft measures directional, differential intensities for ions and electrons in the range 50 eV < E/Q < 45 keV. This range is divided into 15 energy passbands, each of which is subdivided into 16 angular sectors during each spacecraft spin. The field of view of the analyzer is centered nearly on the ecliptic plane. For further details the reader is referred to Frank (1967). The top four panels and the lowest panel on the E-t spectrogram for IMP-8 data correspond respectively to the five panels of the ISEE spectrogram. An example is shown in Plate 1B.

The Goddard Space Flight magnetometer on IMP-8 provided the three-dimensional magnetic field vectors. In this analysis 15.36 second averages have been used. Further information can be found in Ness (1970) and Mish and Lepping (1976).

The ISEE-1 medium-energy particles experiment (Williams et al., 1978) is used to provide higher time resolution information concerning the intermediate-energy plasma flow, and details of gradients in the plasma.

3. Data and Analysis

On May 19, 1978 both ISEE satellites and IMP-8 were in the magnetotail. The orbits for ISEE-1 and IMP-8 are shown in Figure 1 for this day. The striking feature in the ISEE spectrogram is the periodic dropout and reappearance of the plasma, starting at 0930 UT and continuing until 2300 UT. In addition both ions and electrons are more energetic during the extended periodic interval than during the immediately preceding period (0400-0900 UT). This is particularly evident in the sudden change in electron energy at 1030 UT. The energization of the plasma appears to occur coherently over a number of the events, i.e. the energy increases in each successive burst, up to a maximum at 1900 UT, and decreases after 2000 UT.

A plot of the H component of several ground-based magnetograms, obtained from the World Data Center (A), is shown in Figure 2. Identification of the symbols used for the various stations, together with their positions, is given in Table 1. From these signatures it is clear that there is sustained magnetic activity over approximately 10 hours. The enhancements of the H component (or X component in the case of Fort Churchill and Great Whale River) are also periodic, with a period of 1-2 hours. This behaviour is also evident in the Alberta chain of stations over the same interval of time (G. Rostoker, private communication, 1982). The electrojet activity appears to be centered within a narrow latitudinal range from 65° to 69°, with the largest fluctuations seen at Fort Churchill. Weak activity begins at 0800 UT near local midnight at the northernmost stations in this range (Fort Churchill and Great Whale River), as seen in the intensification of the westward electrojet. At the same time an increase in eastward electrojet activity is seen at College and Barrow, and by 1000 UT auroral activity has expanded southwards past these two stations. Dixon and Sodankyla are both on the dayside and show the same periodic

increases in electrojet activity but with time delays in the onsets. The AE index (not shown) begins to rise shortly after 0800 UT and reaches a peak of 400γ at 0940 UT.

It is clear that periodic substorm-associated activity occurs on this day. However the rapid sequence of events makes it difficult to assign an onset time to each event, or even to decide whether each negative H bay should be considered as separate from the others. The length of time between separable substorms has variously been estimated as approximately an hour (Rostoker et al., 1982) to 2-3 hours (McPherron, 1978). In addition there does not appear to be an agreement on the minimum electrojet intensification required to constitute a substorm (Rostoker et al., 1980). It is possible that the entire active interval on May 19, 1978 consists of a single storm with multiple surges, or that a series of weak substorms occurs.

Figure 3 shows the plasma and magnetic pressure observed on ISEE-1, where the rises and dropouts can be clearly seen in both quantitites. In addition in the lower panel is shown the magnetic field data from IMP-8. This shows sharp southward turnings a number of times during the interval 1100-1500 UT. (Between 1600 and 1700 UT the satellite was engulfed by the plasma sheet which provides for some two-satellite comparisons.) As IMP-8 is in the magnetosheath during the intervals of negative B_z it is clear that the interplanetary field rotates southwards a number of times during this period (Fairfield, 1976). Such sharp southward turnings are usually correlated with increases in geomagnetic activity in most substorm studies (Rostoker et al., 1980).

The appearance and disappearance of the plasma can thus be attributed to thinnings and subsequent recovery of the plasma sheet due to substorm activity (Hones et al., 1967; Hones et al., 1971; Lui et al., 1975). From Figure 1 it

can be seen that for most of this period ISEE is situated near the northern boundary of the plasma sheet, towards dusk. This boundary region is thought to respond most rapidly and dramatically to substorm expansions (DeCoster and Frank, 1979; Williams, 1981). The spacecraft is also appropriately positioned to observe the effects of neutral line formation, if any, since its X_{GSM} position varies from 10 to 15 R_E from the earth.

The first sign of activity in the tail is seen at 0900 UT. The distribution prior to this time is shown in Plate 2A. The ions, particularly as seen in detectors 3P, 4P and 5P, show a distinct sunward-directed anisotropy. Flow values at this time (in GSM coordinates) in the ecliptic plane are V_x = 44 km sec^{-1}, V_y = 9 km sec^{-1}. The electron intensities also exhibit field-aligned anisotropy in detectors 3E and 4E. The ion temperature is low, around 1 keV. Such distributions are not uncommon near the flanks of the plasma sheet, and may indicate the penetration of cool boundary layer plasma (Eastman et al., 1976) into the plasma sheet where return flow and/or isotropic distributions may be seen.

The distribution at 0906 UT is snown in Plate 2B. The anisotropy in the ions has reversed - the distribution is now peaked in the tailward direction, with V_x = -24 km sec^{-1}, V_y = 3 km sec^{-1}. The bulk of the electron distribution is below the lower energy cutoff of 215 eV for this mode. At 0923 UT the distribution of ions has again reversed, with the peak intensity directed sunwards. During this time an expansion is observed at Fort Churchill, beginning at 0840 UT. Thus the plasma sheet thinning associated with this onset would place the satellite further out along the upper flank of the plasma sheet where the antisunward boundary layer distribution is sampled. Recovery begins

at Fort Churchill soon after 0900 UT. No energization of the plasma is apparent at the satellite position, and there is little evidence of high-speed streaming.

The first plasma dropout occurs at 0920 UT with subsequent recovery at 1030 UT. Thereafter the thinnings and recoveries take place seven times in approximately 12.5 hours. From Figure 3 it can be seen that the energy density during the plasma bursts increases to a peak value of 1.1 keV cm^{-3} at 1920 UT. During the following two bursts this decreases sharply. On the ground there is also a gradual increase in westward electrojet intensity at various stations, followed by gradual recovery. After 1800 UT very little auroral activity is seen (see Figure 2).

An $E-\phi$ spectrogram at 1629 UT, one of the times when plasma dropout occurs, is displayed in Plate 2C. The electron intensities appear to be isotropic, while the ions exhibit a weak anisotropy. The bulk of the plasma may be present below 215 eV and could show the anisotropy seen earlier at 0830-0930 UT. Both density and temperature are low. Such cold, weakly anisotropic distributions recur throughout the 12.5 hour period whenever the plasma sheet thins below the satellite.

A typical example of one of the plasma bursts is shown in Plate 2D. At 1928 UT the ion density and temperature appear to be enhanced. A lower cutoff in the ion distribution is seen at a few hundred eV. Again the ions are only weakly anisotropic and remain so throughout the interval. At higher energies, however, there is clear indication of field-aligned anisotropies. Counter-streaming 35 keV ions are observed flowing along magnetic field lines. The counter-streaming is dynamic, showing considerable variation within the interval when the burst occurs. These observations are in agreement with those of

Williams (1981), who suggested that they were the result of a deep-tail acceleration process, with subsequent mirroring near the earth to create the return beam. The portion of the distribution that exhibits such streaming is very small, and it is clear that the bulk of the ion population is stably trapped even during the enhanced ion bursts. Temporal variations in the bulk plasma which occur on a scale shorter than the instrument cycle time of 8 minutes are in general small. The major characteristics of the velocity distribut as seen at 1928 UT and during other plasma bursts persist over several cyc .

The electron intensities show distinct field-aligned anisotropies at UT and during the other periods of enhanced plasma pressure. Such signatures are often seen in the plasma sheet boundary layer where field-aligned current sheets are frequently present (Frank et al., 1981). A direct measurement of the current carried by the electrons is possible. By using the simultaneously measured magnetic field deflection the current sheet intensity can be obtained, and thus an estimate of the thickness of the current sheet can be made. Evaluation of the thickness of the current layer using the plasma velocity and the time interval during which the currents are detected lead to large uncertainties as the time needed to obtain a statistically significant velocity measurement in this tenuous plasma is long (several minutes) relative to the sampling time ($\lesssim$ 2 minutes) for the currents. Thus the value of $\vec{V}$ used in any calculation may not accurately reflect the instantaneous velocity at the time the currents are observed.

The electron distribution function for the instrument cycle at 1928 UT is shown in velocity space in Figure 4. Contours of constant $F(\vec{V})$ are plotted as a function of $V_\parallel$ and $V_\perp$, the velocities parallel and perpendicular to the magnetic field, respectively. The units of F are $sec^{-3}\ cm^6$. The bulk of the current

comes from lower energy electrons, at about 1 keV (see Plate 2D). This corresponds to the innermost contour, where a clear anisotropy directed along $-\vec{B}$ is seen. The net integrated current density is 2.54×10^{-8} A m^{-2}, directed along $+\vec{B}$. This is well above the estimated threshold of 2×10^{-9} A m^{-2} for the instrument, and is in general agreement with previous observations (Frank et al., 1981). In calculating the current density we have assumed that the charge-carrying species is electrons and have ignored ion contributions. As the ions are quasi-isotropic throughout with low bulk flow velocities (less than 50 km sec^{-1}) this assumption is well justified.

Table 2 shows the values of $J_{\parallel}$ at a number of different times during the day, with the magnetic field deflection and estimated current sheet thickness at those times. The current sheet is noticeably thinner than the plasma sheet boundary layer itself, which has been estimated as $\lesssim$ 1-2 R_E using two IMP spacecraft (DeCoster and Frank, 1979). These current signatures appear during the plasma bursts for several instrument cycles, although their intensity varies during the approximately hour-long burst. This suggests that the current sheets may be filamentary in structure with some temporal variation seen within each filament.

We can also make an approximate evaluation of the diamagnetic current due to the pressure gradient in the following way:

$$\vec{J}_{\perp} = -\frac{\vec{\nabla} P \times \vec{B}}{B^2} \quad .$$

We have determined that the motion of the plasma sheet is essentially in the z_{GSM} direction (see later section on expansion velocities), so that the pressure gradient term can be replaced by $dP/dz\ \hat{z}$. Knowing the value of $(V_z)_{GSM}$ and the temporal rate of change of the pressure term we can estimate $\vec{J}_{\perp}$ by

$$\vec{J}_\perp = -\frac{1}{V_z}\frac{dP}{dt}\hat{z} \times \frac{\vec{B}}{B^2} \quad .$$

At 1521 UT the pressure gradient is -4.5×10^{-18} erg cm^{-4}, which gives rise to a diamagnetic current of

$$\vec{J}_\perp = 2.5 \times 10^{-9} \text{ A m}^{-2} \quad ,$$

i.e., the perpendicular current is approximately an order of magnitude smaller than the field-aligned current evaluated at this time. Part of the magnetic deflection is due to this perpendicular current which is relatively large at each of the expansions and contractions of the central plasma sheet.

During the cycles when we have evaluated the field-aligned current densities the currents are all directed into the ionosphere. This agrees with the observations of Iijima and Potemra (1976) who found that in the premidnight sector region 2 currents, which are directed into the ionosphere, are dominant. We do not see any currents of opposite sign. However, as noted earlier the main electrojet activity is restricted to a narrow latitudinal range, between 65° and 69° so that the region sampled maps to region 2 (Iijima and Potemra, 1976; Saflekos et al., 1982).

We can estimate the distance from the satellite to an absorption boundary by using the technique described by Williams (1979). Using the medium-energy particle detector, gradients in the plasma can be sounded and the distance to these gradients calculated. For this day the distance from the satellite to the lobe has been sounded for several intervals. Table 3 lists a series of such distance estimates as a function of time in one plasma pulse. The plasma sheet boundary layer thickness is thus seen to be < 2400 km during this interval. However the thickness is clearly a dynamic quantity related to substorm

activity. The plasma sheet boundary layer may be regarded as a primary transport region during active times, characterized by time-varying high-speed streaming distributions (DeCoster and Frank, 1979) which are created by a deep-tail source (Williams, 1981).

From the electron signatures throughout the 12.5-hour interval it appears that both spatial and temporal variations associated with substorm activity occur in the plasma sheet boundary layer. The plasma dropouts are due to thinning of the plasma sheet below the spacecraft position. The reappearance of the plasma is accompanied by filamentary current signatures which show temporal intensity variations during the recovery period. The extent of the activity is limited, both in spatial extent and intensity. Energization of ions and electrons is only apparent at the start of periodic activity at 1030 UT. After the initial observation of the hotter plasma the periodic dropouts and reappearances do not indicate any significant further energization. Instead the ion thermal energy decreases after 1530 UT. At this time the value of kT is 5.3 keV, at 2200 UT it has decreased to less than 2 keV. This energy pattern may indicate that each plasma burst is not an isolated event but may be part of a larger system with small-scale features, e.g. multiple surges within a substorm. As we have suggested earlier the periodicity may be linked to the periodic switching of the interplanetary field latitudinal component. It has also been noted by Akasofu (1977) that if a perturbation occurs after a period of southward B_z in the interplanetary field, the magnetosphere can show more than one response, as if pumping down from an excited to a ground state in stages.

The plasma sheet response is, as we have pointed out above, limited in spatial extent, as indicated by ground-based magnetograms. Observations made

by IMP-8 indicate that between 1619 and 1648 UT the plasma sheet expands past this satellite. Before and after this interval the spacecraft is in the magnetosheath or boundary layer. During the same time that the plasma sheet is expanding at IMP-8, the LEPEDEA on ISEE-1 observes a dropout indicative of plasma sheet thinning. From Figure 1 it is clear that the two satellites are widely separated throughout the day, particularly in the Y component. The disparity in response confirms our earlier conclusions that the active region is spatially limited, and indicates that a global approach to substorm dynamics via magnetic merging with the concept of a cross-tail neutral line is not always appropriate.

In order to estimate the rate at which the plasma sheet recovers, we have utilized two-spacecraft measurements made by the U. C. Berkeley energetic particle instruments on ISEE-1 and -2 (Anderson et al., 1978). The general method used is to identify distinctive similar features in the flux observations at ISEE-1 and -2, and estimate the time delay between the two. Knowing the spacecraft separation we are then able to calculate an expansion velocity. Comparison of these expansion velocities with the bulk velocity of the plasma as measured simultaneously by the LEPEDEA indicates that expansion takes place primarily in the z direction. The results are shown in Table 4. These values are in good agreement with those measured previously (Hones et al., 1970; Parks et al., 1979; DeCoster and Frank, 1979).

We can also make an estimate of the energy flux during one of the plasma enhancements. At 1728 UT the bulk velocity is 29 km sec^{-1}, ion density is 0.16 cm^{-3} and thermal energy 4.4 keV. The energy flux is then

$$F = 3.3 \times 10^{-3} \text{ erg cm}^{-2} \text{ sec}^{-1} \quad .$$

Assuming an average half-thickness of the plasma sheet to be 2 R_E, and a width of 30 R_E gives an input power of energy production of at least 8 X 10^{16} erg sec^{-1}. As we have no observations of the central plasma sheet, where temperatures and densities are likely to be higher at this time, this estimate gives a lower limit to the total value expected. The average duration of the plasma bursts is 1 hour, giving a total energy input of 2.9 X 10^{20} ergs. This agrees with the value for a weak substorm (Akasofu, 1977, p. 561).

4. Conclusions

On 19 May 1978 an unusual 12.5 hour interval of quasi-periodic plasma bursts is observed in the tail by ISEE-1. At the same time ground-based magnetograms show periodic intensifications of the electrojets and there are strong southward fluctuations in the interplanetary magnetic field. We thus conclude that the plasma observations are due to substorm activity which causes periodic thinning and expansion of the plasma sheet. The spatial extent of the tail activity appears to be limited, as (1) the latitudinal range in which the bulk of the electrojet intensification is seen is restricted to about 4°, and (2) IMP-8 which is approximately 10 R_E tailwards of ISEE observes plasma sheet expansion at a time when there is a dropout due to thinning at ISEE. Thus the observations at ISEE indicate temporal and spatial variations within a relatively local region.

An analysis of the plasma observations has been carried out. This reveals that throughout the disturbed interval the plasma exhibits weak anisotropy. Counter-streaming energetic ions are observed at the same time as the lower energy distribution, but these flowing ions constitute a small percentage of the total population. During the plasma dropout the statistics on the high-energy ions are too poor to determine whether high-speed flows are present. The low-energy ions remain quasi-isotropic, although larger anisotropies may be present below 215 eV.

During the plasma bursts the electron intensities show distinct field-aligned anisotropies. These have been integrated directly to yield current densities which range from 1.7×10^{-8} A m^{-2} to 2.5×10^{-8} A m^{-2}, in agreement with previous measurements. Comparisons with current intensities estimated from the magnetic field observations on ISEE indicate that the current-carrying sheets are narrow, generally a few hundred kilometers thick. This

suggests that the plasma sheet boundary layer, generally thought to be several thousand kilometers in thickness, has either a relatively limited current sheet structure, or that the current sheet is filamentary in nature.

The electron anisotropies and ion streaming vary temporally as well as spatially. The velocity distributions indicate that the spacecraft is in a plasma sheet boundary which undergoes temporal change throughout the interval. The substorm activity is accompanied by repeated thinning and recovery of the central plasma sheet. Hence ISEE samples different spatial regions of a dynamically varying boundary layer.

The rapid sequence of events makes it difficult to establish whether each plasma burst is an isolated weak substorm. However the pattern of a gradual increase in the plasma pressure in successive cycles, followed by a gradual decrease suggests that we are observing an active period in which multiple surges occur. The periodicity of these surges may be due to the rapid changes in the interplanetary field. A possible mechanism for multiple onsets is the streaming tearing mode (Sato and Walker, 1982) in which an initial field-aligned flow enhances the growth rate of the instability.

This case is difficult to interpret in the framework of the conventional near-earth neutral line model. Two-satellite observations indicate that the disturbance is local and not global in extent. The magnetic field at ISEE shows no sharp rotations, as predicted by the model. In addition plasma drop-out and consequent high-speed streaming are absent. The bulk of the population remains stably trapped, while higher energy ions show simultaneous counter-streaming. The events on this day indicate that a limited spatial region in the tail can show dramatic response to substorm activity, in the form of repeated thinnings and recoveries. Other observational features

regarded as typical of active periods (magnetic field rotation, plasma drop-out, etc.) do not predominate for this case, despite the favorable position of ISEE for detection of such features.

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Plate Caption

Plate 1. (a) ISEE-1 E-t spectrogram for 19 May 1978, showing repeated plasma bursts between 0930 UT and 2300 UT.

(b) IMP-8 E-t spectrogram for the same day, showing magnetosheath signatures except during 1600-1700 UT when the satellite is in the plasma sheet.

Plate 2. (a) Distribution at 0840 UT on 19 May 1978, showing anisotropic ion responses. (Feature in frame 5E should be ignored.)

(b) E-ϕ spectrogram for the following cycle where the anisotropy in the ion distribution has reversed direction. (Feature in frame 5E should be ignored.)

(c) Typical sample taken during a plasma dropout.

(d) Response during an enhancement, showing increased plasma pressure and field-aligned electron anisotropies.

Figure Captions

Figure 1. Orbits of ISEE-1 and IMP-8 spacecraft on 19 May 1978. The time in hours (UT) is indicated on each graph.

Figure 2. Ground-based magnetograms from six auroral-zone stations, showing periodic intensifications of the electrojets.

Figure 3. The top panel shows the variation in plasma and magnetic pressure observed at ISEE-1. The diamagnetic effect is clearly seen. The lower panel displays the total magnetic field $|B|$, and latitudinal component B_θ, detected by IMP-8, where strong southward rotations are evident.

Figure 4. Contours of phase space density plotted relative to the magnetic field direction for electrons detected at 1928 UT. The inner contour shows a net drift along $-\vec{B}$, giving a field-aligned current of 2.54×10^{-8} A m^{-2}.

Table 1: Magnetometer Stations

Symbol	Station Name	Geomagnetic Latitude	Geomagnetic Longitude	Local Midnight (UT)
DI	Dixon	63°	162°	1748
BA	Barrow	68°	241°	1235
CO	College	65°	256°	1133
FC	Fort Churchill	69°	323°	0704
GWR	Great Whale River	66°	347°	0526
SO	Sodankyla	64°	120°	2032

Table 2: Current Densities

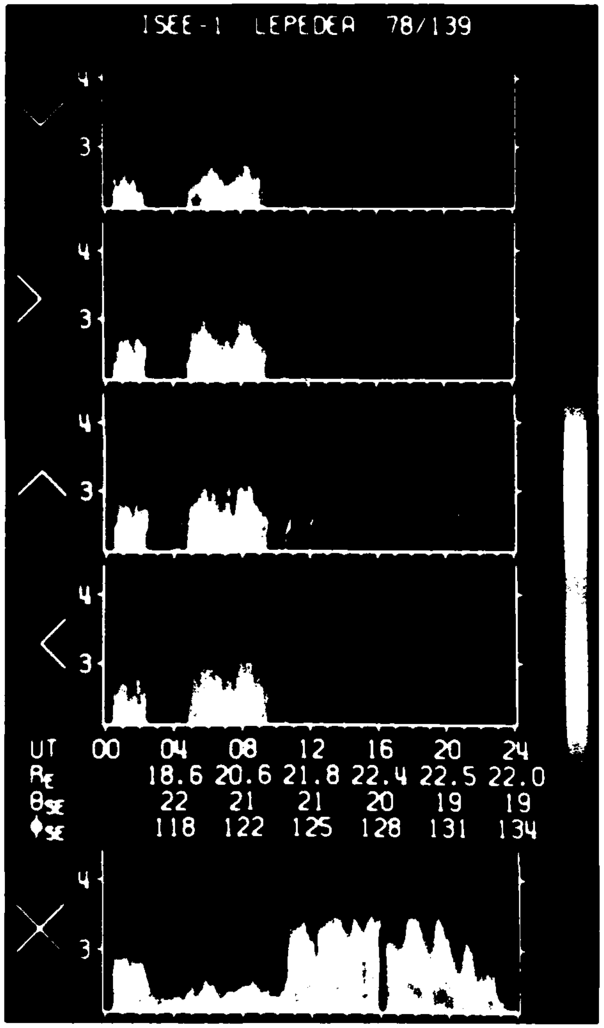
Time (UT)	$J_{\parallel}$ (A m^{-2})	$\Delta B_y(\gamma)$	ΔZ(km)
1339	1.66×10^{-8}	6	289
1521	2.27×10^{-8}	5	201
1555	2.03×10^{-8}	12	473
1911	1.92×10^{-8}	4	167
1928	2.54×10^{-8}	5	157

Table 3: Distance from ISEE-1 to Lobe

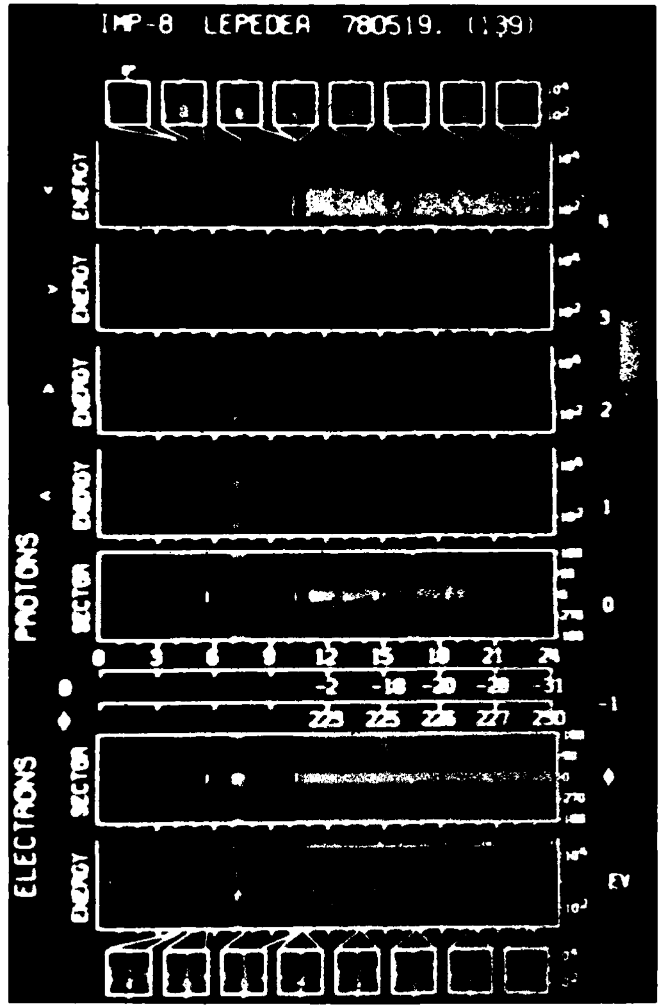
Time (HHMM:SS)(UT)	d(km)
1337:47	48 ± 24
1338:23	516 ± 168
1339:00	1980 ± 32
1339:36	>2400
1340:12	2232 ± 96

Table 4: Expansion Velocities

Time	Estimated V_z (km sec^{-1}) (spacecraft coordinates)
1212	15
1424	25
1500	15
1640	16
1947	15
2117	12


ISEE-1 LEPEDEA 78/139
UT 00 04 08 12 16 20 24
R_E 18.6 20.6 21.8 22.4 22.5 22.0
θ_{SE} 22 21 21 20 19 19
ϕ_{SE} 118 122 125 128 131 134

A


IMP-8 LEPEDEA 780519. (139)
PROTONS
ELECTRONS
ENERGY
SECTOR
EV

B

Plate 1

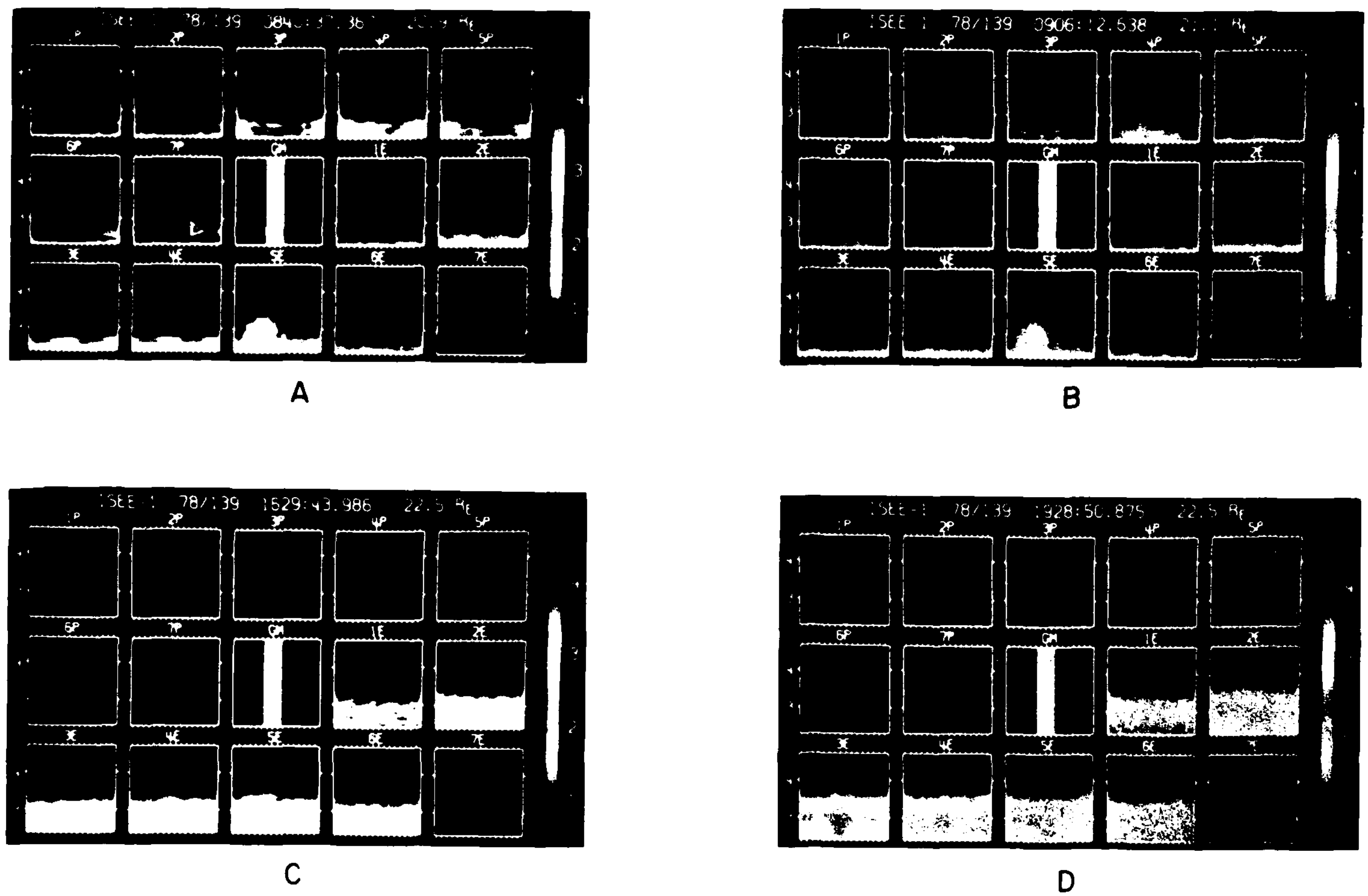

ISEE 1 78/139 0906:12.538
ISEE-1 78/139 1529:43.986 22.5 RE
ISEE-1 78/139 1928:50.875 22.5 RE
A
B
C
D

Plate 2

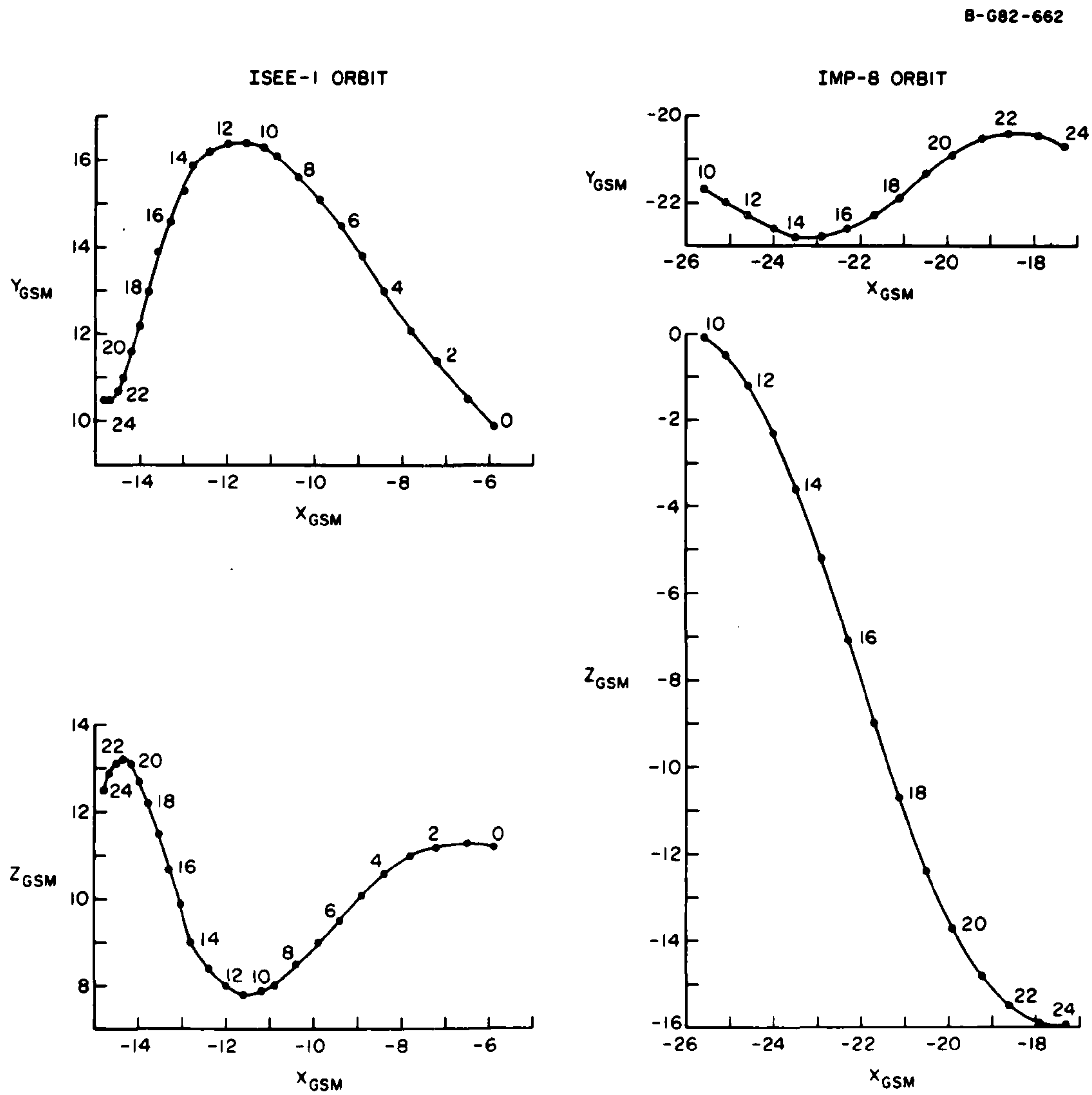

B-G82-662
ISEE-1 ORBIT
IMP-8 ORBIT
YGSM
ZGSM
XGSM
12
10
14
16
8
6
4
2
0
18
20
22
24
-14
-12
-10
-8
-6
-26
-24
-22
-20
-18
-16

Figure 1

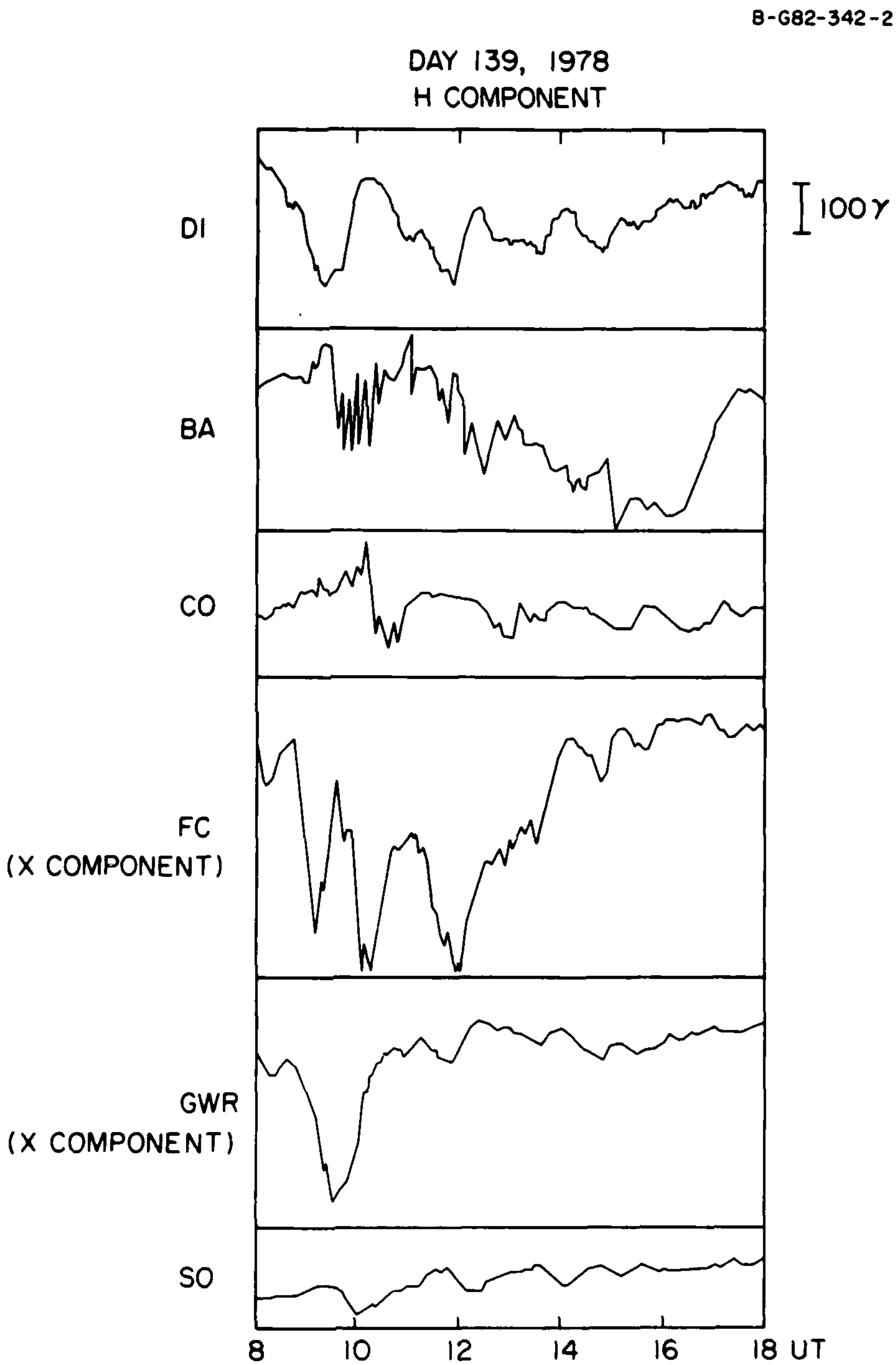

B-G82-342-2
DAY 139, 1978
H COMPONENT
100γ
DI
BA
CO
FC
(X COMPONENT)
GWR
(X COMPONENT)
SO
8
10
12
14
16
18 UT

Figure 2

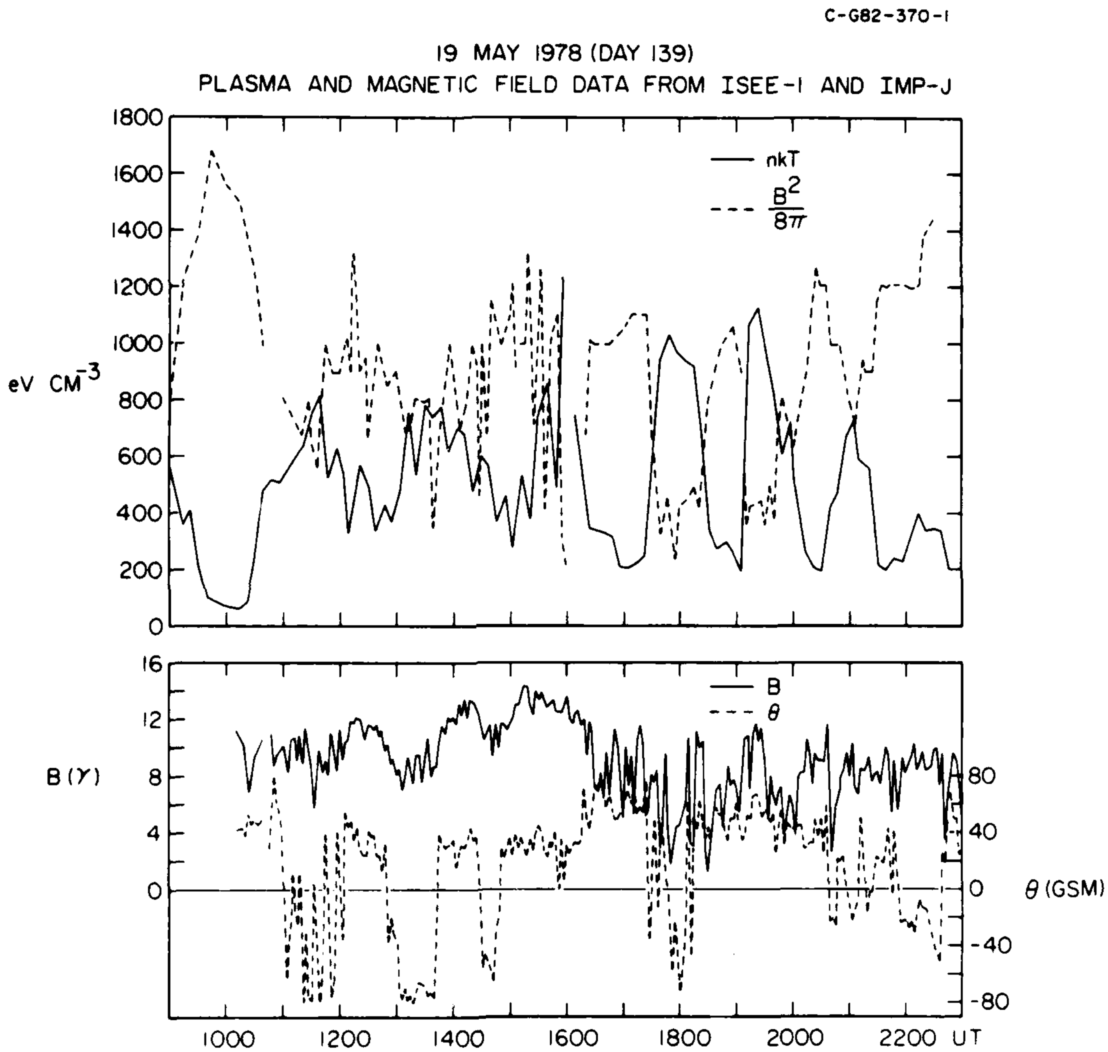

C-G82-370-1
19 MAY 1978 (DAY 139)
PLASMA AND MAGNETIC FIELD DATA FROM ISEE-1 AND IMP-J
nkT
$\frac{B^2}{8\pi}$
eV CM^{-3}
1800
1600
1400
1200
1000
800
600
400
200
0
B
θ
B (γ)
16
12
8
4
0
80
40
0
-40
-80
θ (GSM)
1000
1200
1400
1600
1800
2000
2200 UT

Figure 3

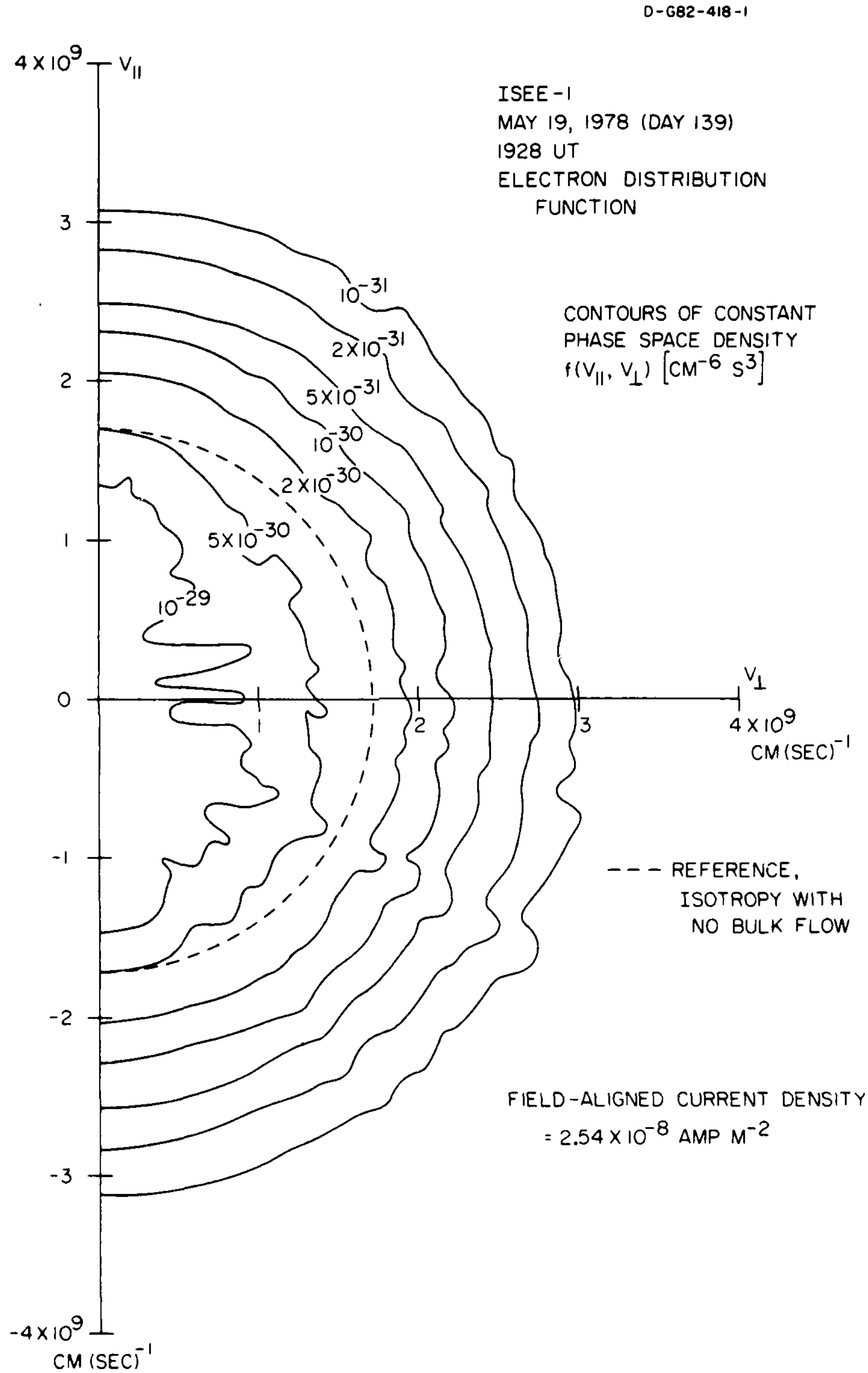

D-G82-418-1
4×10^9
$V_{\parallel}$
ISEE-1
MAY 19, 1978 (DAY 139)
1928 UT
ELECTRON DISTRIBUTION FUNCTION
CONTOURS OF CONSTANT PHASE SPACE DENSITY
$f(V_{\parallel}, V_{\perp})$ $[CM^{-6}\ S^3]$
10^{-31}
2×10^{-31}
5×10^{-31}
10^{-30}
2×10^{-30}
5×10^{-30}
10^{-29}
$V_{\perp}$
4×10^9 $CM(SEC)^{-1}$
--- REFERENCE, ISOTROPY WITH NO BULK FLOW
FIELD-ALIGNED CURRENT DENSITY $= 2.54 \times 10^{-8}$ AMP M^{-2}
-4×10^9 $CM(SEC)^{-1}$

Figure 4

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On 19 May 1978 an unusual series of events is observed with the Quadri-spherical LEPEDEA on board the ISEE-1 satellite in the earth's geomagnetic tail. For 13 hours periodic bursts of both ions and electrons are seen in all the particle detectors on the spacecraft. On this day periodic activity is also seen on the ground, where multiple intensifications of the electrojets are observed. At the same time the latitudinal component of the interplanetary magnetic field shows a number of strong southward deflections. We conclude that an extended period of substorm activity is occurring, which causes repeated thinnings and recoveries of the plasma sheet. These are detected by ISEE, which is situated in the plasma sheet boundary layer, as periodic drop-outs and reappearances of the plasma. Comparisons of the observations at ISEE with those at IMP-8, which for a time is engulfed by the plasma sheet, indicate that the activity is relatively localized in spatial extent. For this series of events it is clear that a global approach to magnetospheric dynamics, e.g., reconnection, is inappropriate.

4-8

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